Wolf Tracker
Night-Vision Guidance System

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Contents

1 Challenge Definition Restated

One of the main issues that are faced by researchers at the California Wolf Center is the ability to survey their wolves at night. This has been an import issue for the Wolf Center because the wolves are most active at night, and current methods of media capturing have been adequate at best. The main challenges surround this issue involve finding a vehicle that can effectively handle the terrain, overcoming the curiosity of the wolves, and minimizing the amount of human contact that the wolves encounter.

Current methods of recording data involve visible light cameras positioned around the enclosure. These cameras are costly and ineffective when they need to cover a large area. Furthermore, cameras hidden throughout the terrain tend to capture images and recordings with a fixed perspective, not always showing the wolves' full behavior. Equally, the field of view must be large to increase the chance of capturing an animal. Problems linked to these systems also include destruction by the animal, and the need of entering the enclosure to modify its mounting. Additionally, night time surveillance camera systems tend to lie around the price range of at least $3000, leaving researchers with a system that they rapidly become disappointed in.

Handling the terrain itself is a very difficult challenge for most non-camera solutions. The enclosure is filled with large rocks, holes dug by pups, tall grass, sand, mud, dead carcasses, and rests on a 30 degree incline. If a quad copter were to be used, the vehicle would have very low battery longevity and would be difficult to control. A remote airplane would be able to survey the entire area, but would not be able to capture the close-quarters media that would be ideal.

Additionally, the wolves are highly intelligent and will investigate new objects in their environment. This investigation can include gnawing, scratching, sniffing, and urinating, actions which can be harmful to both the vehicles and the wolves. Therefore, the solution must be able to withstand the force of the wolves while being clear of sharp edges and loose items which could bring harm to the wolves. Essentially, the vehicle must be fully self-contained.

Aside from these constraints, the vehicle must have as small a footprint as possible. If the wolves become afraid of the vehicle then the vehicle will not be able to capture genuine footage and will be useless. In order to achieve this, the vehicle must be as quiet as possible. This feature is perhaps the most critical because it is the goal of the research center to keep the animals as “wild” as possible so that they may be released out of captivity. To maintain this, the animals must receive as little human contact as possible.

Finally, the vehicle must be easy to use. If the vehicle is not user-friendly then our vehicle will not be able to induce the kind of impact that would strongly contribute to the efforts of researchers not only at the Wolf Center, but to other researchers around the world.

2 Project Solution Updated

In order to overcome these challenges, we have decided that a land vehicle will provide the Wolf Center with the best option. Our vehicle provides an affordable, easy-to-use platform that can capture media while enduring harsh environmental factors.

2.1 Terrain-handling

Our vehicle provides full six-wheel drive, granting the ability to move over terrain should some of the tires lose traction. Just as well, the vehicle provides a ground clearance of approximately 3" with 10" diameter wheels in order to successfully navigate over the large rocks, tree roots, and holes that were observed at the Wolf Center. Additionally, the chassis of the vehicle is durable so as to prevent destruction of internal components should the vehicle undergo impact with a tree or rock.

2.2 Wolf-handling

The curious nature of the wolves has been a major part of the design process. To prevent the wolves from biting and chewing off parts of our vehicle we have designed our vehicle such that each area of the vehicle is larger than 10" from every angle, a metric which we have found to be a larger than the jaw of the wolves.

To further protect our external camera, we have implemented a dome to be placed over our camera gimbal in order to prevent the wolves from grasping the camera with their teeth. The dome, as well as the chassis, will be water-tight so as to prevent fluids from damaging the hardware should the wolves urinate on it.

Keeping in mind the Wolf Center's desires to prevent harm from coming to the wolves, all sharp exterior parts of the chassis are covered in order to prevent lacerations. In addition, all electrical components are contained within the interior of the vehicle so as to prevent the wolves from ingesting them.

In order to minimize the footprint of the vehicle, the interior sounds of the atom board and camera gimbal will be contained within the dome. The motors will also not be able to reach full power so as to minimize the amount of audible noise that they generate, for certain given terrains. If necessary, the terrain-handling can be improved by giving the motors more power.

2.3 Media-capture

To obtain the live stream of footage which we will need to monitor the wolves and steer the vehicle, we will be employing the use of a two-axis gimbal capable of rotating 360 degrees on either axis. The gimbal will hold a visible-light webcam for use during the day. For night surveillance, the gimbal will hold an additional near-IR camera and floodlight. The gimbal will allow both cameras to be moved into any desired direction the observer wants on the pan and tilt axis.

2.4 User Experience

In order for our vehicle to be easily operable, we will provide a user interface to simplify operations. To control the vehicle, a wireless Xbox controller will be used so that control of the vehicle may be more intuitive. Just as well, on-screen data such as GPS location, camera orientation, and a live camera stream allow the user to fully understand the environment surrounding the vehicle.

3 Performance Evaluation Overview

Our system will be built with the intention of recording the behavior of wolves at night. The system's effectiveness will be measured based on different characteristic of the vehicle. These are the data measurements we can take to verify the success of our platform.

3.1 Terrain-handling

These measurements will be taken using various data loggers and will be further analyzed. The slope angle test and the step height test will done with increasing marginal slope angles and steps. For the range test, one member will go away from another using the antennas and the signal strength will be recorded. We will consider each domain to be successful when the following specifications will be reached:

- Capable of maneuvering up a 45 degree incline
- Capable of climbing 7"steps
- Capable of traversing tall grass of at least 7"
- Capable of maneuvering over and across large rocks up to 3" in diameter
- Capable of receiving 1500 kbps of wireless data at least 300ft away.

3.2 Wolf-handling

One of the main concerns of the Wolf Center is maintaining the health and safety of the wolves. These aspects will be the main source for the majority of our mechanical design, and will be put to test inside of the Wolf enclosure after careful inspection for the Wolf Center's General Manager, Animal Caretaker, and veterinarian.

- Depreciation of all sharp edges from the design
- No areas small enough to allow a wolf to fully grip the vehicle with its' teeth, approximately 10"
- Water-tight

3.3 Media-capture / User Experience

When considering the ease of operation, we will be testing our platform at the Wolf Center, where actual ecologists test the operation of the vehicle, before fully deploying it. To ensure the platform's effectiveness, we will give specific training to the operators, and will install all necessary equipment. The aim is for our solution to be used without limitation for the designed tasks by the researchers, after us having installed all equipment. The ecologists will regard this solution to be successful when we achieve the following:

- Live video clearly showing the environment, as well as highlighting a mammal at night
- Easy and user-friendly operation of vehicle on applicable terrain.
- Ability to move camera direction to desired position
- Minimum of 640x480 resolution
- Less than one second of command and video delay over wireless communication

4 Technical Documentation

4.1 Hardware

The rover is composed of a shell, which acts simultaneously as a structural support and as a protective layer for the vehicle

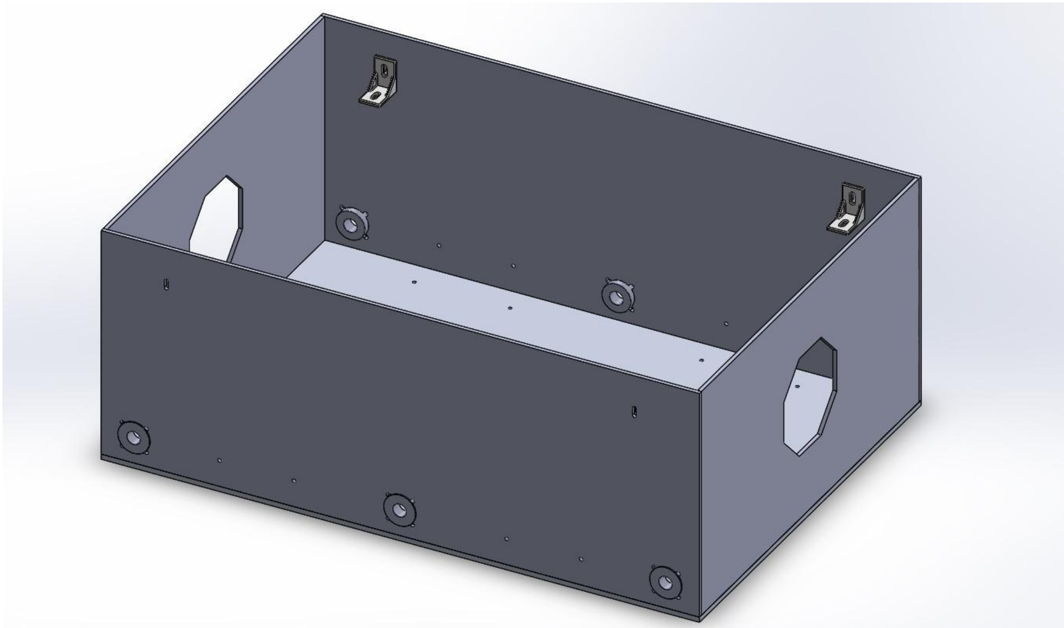
The structure consists of 5 aluminum sheets that compose the “shell” of the car, two supporting aluminum bars, six motors, six wheel shafts, 6 shaft collars, 6 flange bearings, wheels, brackets, and different platforms to support the electronics. For simplicity we are going to explain the significance and importance of each item as well as the details on how to assemble the structure.

To construct the project we first needed 5 aluminum sheets. The aluminum sheets are of different thicknesses, and obviously of different sizes. In particular, the bottom aluminum sheet needs to be thicker so it can easily support the weight of the batteries, motors, shafts, electrical components, gimbal and cameras, and the other aluminum sheets. The other four sheets are thinner in order to save as much weight as possible. For this project we are using 6061 aluminum alloy, with ¼ inches thick for the bottom plate, and 3/16 inches for the rest. The reason for this choice of alloy is for its easy machinability, as well as for its structural properties- lower density and lower deflection under load. The structure is assembled in such a way that the bottom sheet is supporting the other four, in which each one is right on the edge and on top of the bottom sheet. For the manufacturing of the sheets, it is easiest to use a large CNC router table, and with a ¼” end mill do small passes until the whole sheet is cut. With a tool change, you are then also able to accurately drill all holes necessary for later assembly. All the CAD files for this project would be used to create according tool paths. An alternate method consists of using a band saw to do rough cuts, and later doing simple facing using a mill. In this case, you would be using a pillar drill to drill all the holes.

The dimensions of each aluminum sheet are as follow:

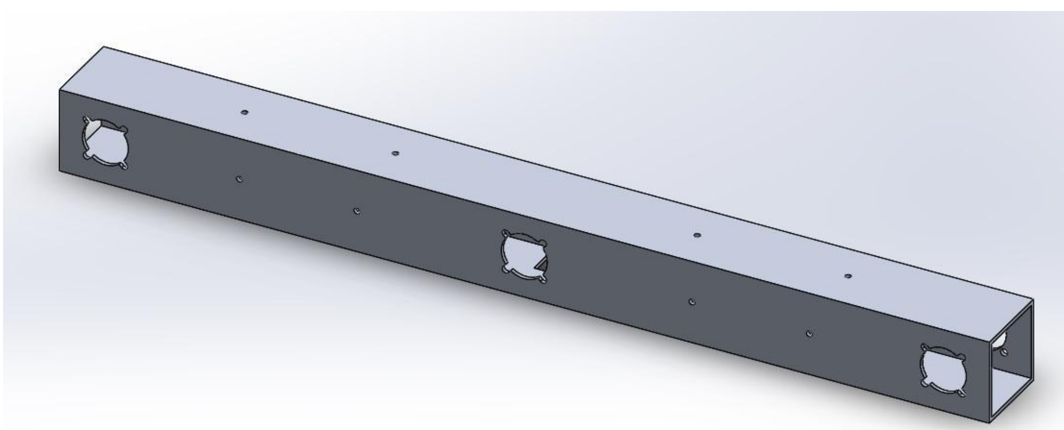
- 36x24x1/4 inches for bottom plate(1)
- 28.125x10.8125x3/16 inches for side plates(2)
- 19.375x10.8125x3/16 inches for front and back plates(2)

Side aluminum sheets also need to include 3 holes of 1 ⅜ inches of diameter for the flange bearings. After the sheets are ready, the structure could be visualized as this:



Next are the aluminum bars. The aluminum bars provide not only extra rigidity to the drivetrain but also an efficient and easy way to mount the six independent motors. The main reason why they are included in the project is to make the flange bearings responsible of supporting the weight of the car on the aluminum bars and not the aluminum sheets or the motor shafts.

Their dimensions are 2.5 X 2.5 inches by 27.75 inches of length.



We also included a hole on top of each aluminum bar in order to access the motor shafts located in the middle. Similar holes on the extremes of the aluminum bars are not needed because shafts are already accessible without the front and back sheets. This will become clearer later on the assembling. For the manufacturing of the drivetrains, it is necessary to mill each side according to the cad file using a ¼” end mill and the necessary drill bits.

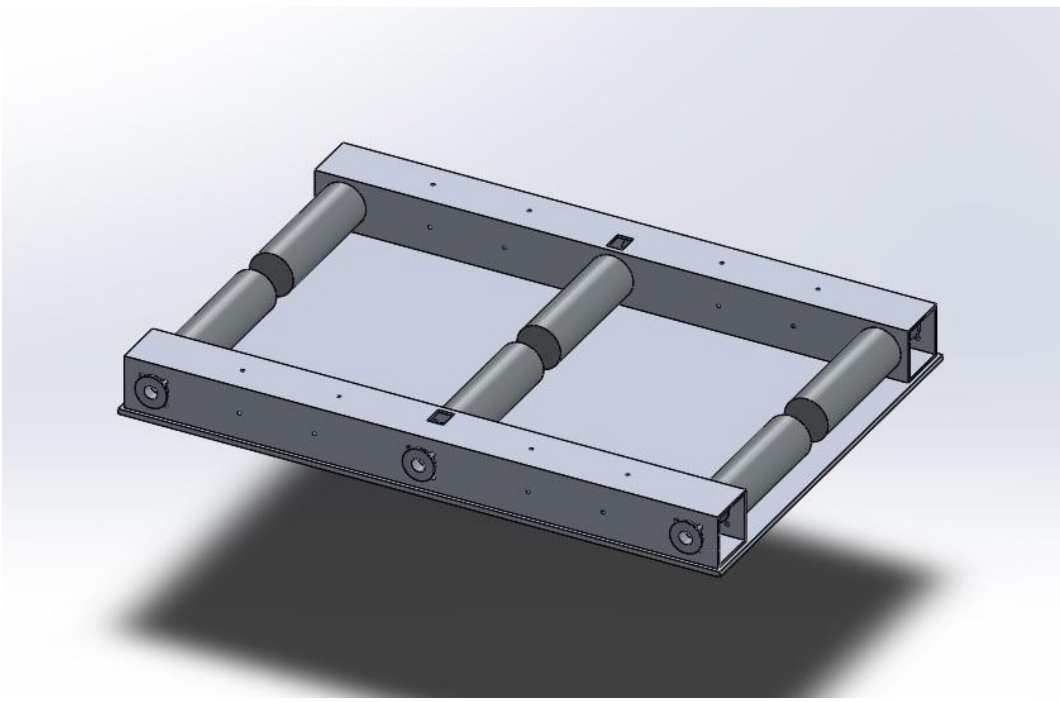
Next in the hardware implementation, the motors and wheels need to be mounted to the drive train. For this project we are using IG52 motors with 12mm diameter shafts and output of 23kgf-cm at a rated speed of 136 RPM. We milled three 32mm diameter holes on each aluminum bar in order to mount the motors perpendicular to the orientation of the bars. We also milled three 1 3/8’’ set of holes on each bar opposite to the motor holes to mount the flange bearings. As stated before, these bearings were included to support the weight of the prototype. To fix the motors in place we also included a set of 4 radially patterned clearance holes (intended for M5 screws) around each motor hole that were drilled through the entire aluminum bar for better accessibility to the motors.

With this specific set-up we are able to mount the wheel shafts transversally inside the bars through the flange bearings to the motor shafts. Shaft collars with set screws were included in order to prevent slip inside the wheel shafts.

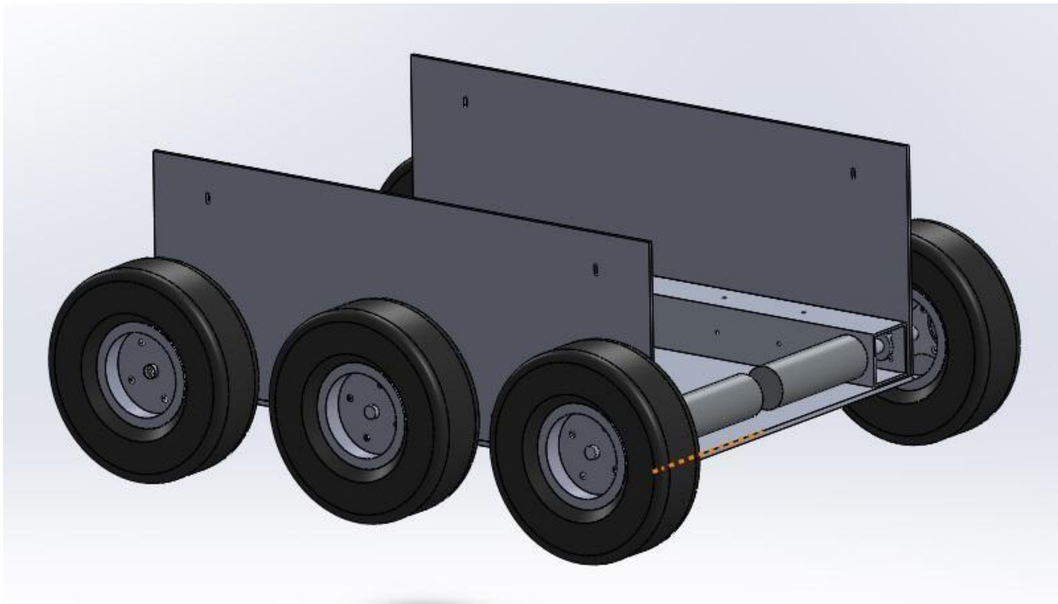
When these components are ready the assembly can start taking shape. The parts are then mounted in this order:

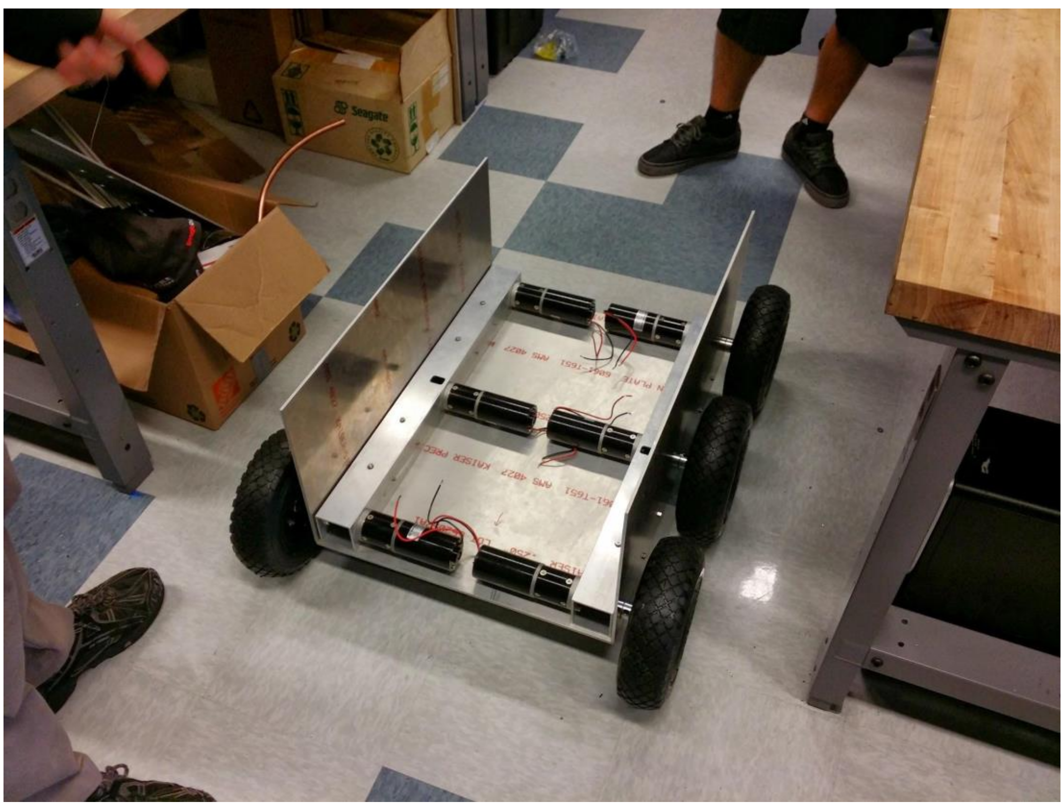
1. First mount the flange bearing and the motors to the aluminum bars
2. Attach the aluminum bars to the bottom plate

The assembly should now look like this:

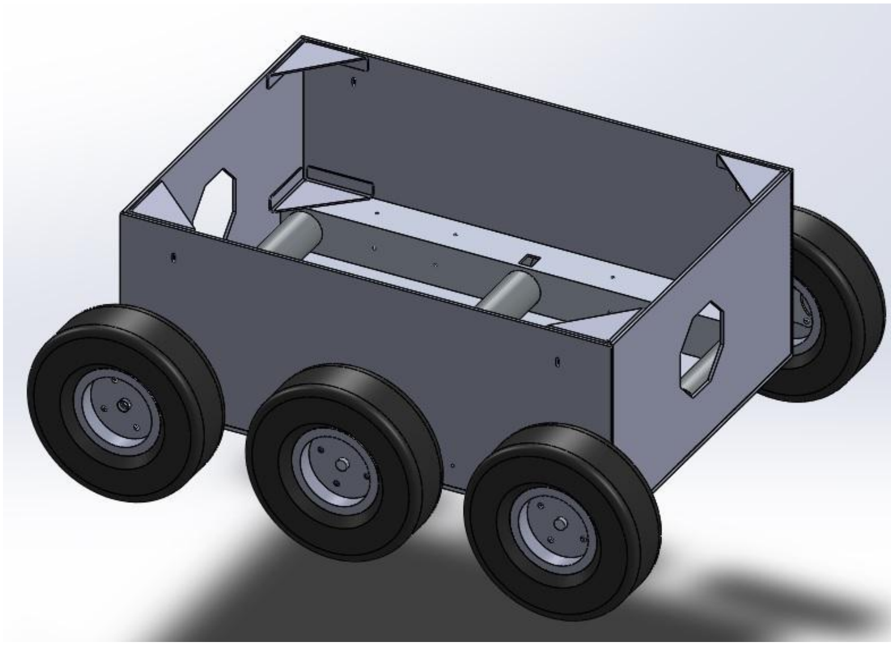


After that is done, we can start mounting the wheel shafts and the side sheets. We first mount left and right sheets and screw them into on the aluminum bars. After that, carefully mount the wheel shafts inside the bearings all the way to the motors. Then carefully use the shaft collars to fix the wheel shafts and motor shafts in place. After include the wheels.





In order to keep front and back plates fixed in place, we need to include corner brackets. These brackets are going to be mounted on top of the aluminum bars and they are going to be located at each corner. Four brackets are going to be resting on top of the aluminum bars and another four at the upper corners of the side plates.



Components

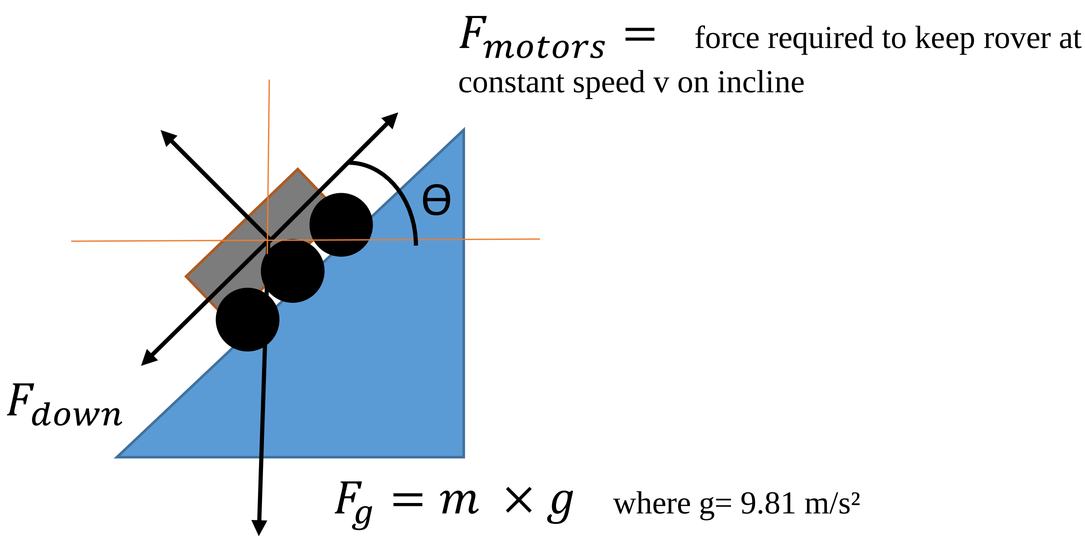
This vehicle required calculations to anticipate what components were going to be used. Initially the design of the rover depended on the size of the wheels we were going to use. Determined by the characteristics the vehicle had to meet, we decided on the vehicle design, and motor choice.

To begin, the size of the wheels was determined by the size of obstacles we were planning to overcome. The criteria was to be able to roll over 1 foot diameter holes, and 10 inch steps. We choose 10" wheels with a separation of 2" between them. This would prevent the vehicle from getting stuck, as well providing sufficient clearance for rolling over small rocks and branches underneath the chassis. The wheels we decided on have a simple, rugged profile, good for off road soil, and traction on steep terrain.

Based on the wheel diameter we were able to consider various motors. We had a design constraint of providing the torque to move the vehicle up on a 45° slope, and the objective to sustain a speed of 1 to 2 m/s.

We omitted friction and resistive forces in our initial calculations, as the modelling would be inaccurate, given the change in environment. We therefore used a safety factor of 1.5 of on the final power output needed to take into account any losses of energy from the system.

Assuming the rover of mass 70 kg is placed on a 45° incline, this is the free body diagram of the system:



Diameter of wheel = 0.254m =10in

$$F_{down} = \cos(45) \cdot 70 \cdot 9.81 = 485.08N$$

$$F_{motors} => 485.08N \times 1.5 = 728\ N$$

$$F_{motors} => 23kgcm \times 25.4cm = 584\ N \times 6 = 3504N$$

$$Speed = pi \cdot 0.254m \cdot\ 136RPM/60s = 1.81m/s$$

The motors we considered are listed in the table below:

Motor	Power(W)	Torque (kg·cm)	RPM (2pi/T)
3271E_0 - 24V/20.3Kg-cm/139RPM 18:1 DC Gear Motor w/Encoder	21.8	20.4	139
IG90 24VDC 127 RPM Gear Motor	80	42	127
IG52-04 24VDC 136 RPM Gear Motor	48.6	23	136

Based on the ratings of the above motors, we decided to go with the IG52 as this motor provided the torque we required to maintain the vehicle in movement on the slope. It was significantly cheaper and lighter than the IG90, which could have been used if we wanted to increase payload significantly.

4.2 Electronics

4.2.1 Sensors

-Potentiometer

-IMU

- Our team is currently utilizing the MPU-9150 which provides nine degrees of freedom - three-axis readouts for a magnetometer, gyroscope, and accelerometer. We decided upon this sensor as it not only interfaces well with the Arduino as well as allows us to detect the tilt and orientation of our robot using either the gyroscope or the accelerometer as well as our compass direction with the magnetometer. In its current state, we have decided to forego use of the gyroscope as we found its functionality insufficient for our purposes. As the gyroscope only measures changes in rotation, it does not provide an accurate reading of orientation of the rover if it had not begun in a flat position. The accelerometer, on the other hand, is able to measure the acceleration of gravity which if used, along with some trigonometry, is able to provide the orientation of the robot. The primary problem which arose from doing this was that while driving the robot, the acceleration of driving caused inconsistencies in the readings, but we found them to be accurate enough to find the general orientation which allowed us to detect if the robot was on a significant incline. In addition, once the robot stopped moving once again, we are able to once again detect the absolute orientation of the rover. For future improvements, we have considered integrating the gyroscope as well in order to detect the changes in orientation while moving the robot and then checking the values against the accelerometer when the rover has stopped moving for a long period.[1]

[1] "Using the Accelerometer – HUSSTECH." *HUSSTECH*. Husstech, n.d. Web. 21 Apr. 2014.

- With information about the orientation of the robot, we are able to detect if the rover is in driving into a steep incline. If the terrain begins to become dangerous for the rover to drive on, we can send a warning to the driver to back away from the area being approached. In addition, we can use this information to find out what direction we need to produce a stall current on our motors so that the rover won't roll on an incline.[2]

-GPS

- We are utilizing a High Performance Active GPS Antenna with the UBLOX NEO-7N GPS/GNSS receiver board in order to obtain GPS information. Our team noticed UBLOX NEO-7N included the option of a USB interface which would allow for us to process the GPS data directly through the Atom Board as opposed to processing the information on, and further straining the Arduino. Through the USB interface, we are able to parse the data we need from the serial port and transfer the position of the rover to the client. [3]
- By combining the GPS data and the magnetometer data, we are able to view the position of the rover from the GUI in order to have an overview of where it is currently being deployed. In addition, if there is a failure in the system, having the final location of the robots allows the researchers at the Wolf Center to quickly remove the rover from the enclosure and make sure the wolves are away from harm.[4]

-Voltage Sensor

- In order for us to estimate the battery levels in the rover, we designed our own voltage sensor by creating a voltage divider. Doing some research, we discovered that the analog input of the Arduino is optimized for output impedances of 10kOhms or less. Knowing this, we calculated a voltage divider assuming our first resister would be 10kOhms. Using the formula Vout = Vin(R2/R2+R1) and assuming Vout would be 5v, the maximum for Arduino and Vin would be 35v in case of a dramatic voltage spike, we calculated R2 to be 1.6666kOhms. In our final voltage divider, we used a 1k and 0.6k resistor instead as those were more available. In order to get the true reading, we multiply the raw input by (5/1023) - the voltage divided by bits - and then scale it by our voltage divider.[5]

4.2.2 Electrical System

[2] "9 Degrees of Freedom - MPU-9150 Breakout SEN-11486 RoHS Open Source Hardware Has 3D Model." *9 Degrees of Freedom*. SparkFun, n.d. Web. 21 Apr. 2014.
[3] "High Performance Active GPS Antenna." - *CSG Shop*. N.p., n.d. Web. 21 Apr. 2014.
[4] "UBLOX NEO-7N GPS/GNSS Receiver Board with SMA for UAV, Robots." - *CSG Shop*. N.p., n.d. Web. 21 Apr. 2014.
[5] "DIY Amp / Watt Hour Volt Meter - Arduino." *Instructables.com*. N.p., n.d. Web. 21 Apr. 2014.

The electrical system that runs the rover consists of its power and signal systems.

4.2.3 Power System

The power system was designed to support six motors, two servos, a Wi-Fi antenna, and the Atom board. Additionally, the robot is required to run for at least two hours in the wolf enclosure. The importance of the hardware chosen to support this electrical load will be described as well as the assembly.

The six motors that run the robot require both a power distribution board and six motor controllers. The selected IG52 motors drew 2.850 amps (rounded up to 3 amps) at 24 volts. The total wattage draw from the motors is approximated to be 432 watts.

The initial motor controllers, the Sabertooth Dual 12A RC Motor Driver, were found from the same supplier as the IG52 motors. While the motor controllers supported two motors each, the total cost of three motor controllers would be $195. The Cytron 13A 5V-25V motor controller, a cheaper alternative that supported our motor requirements was found at a price of $16.33 per unit, for a total cost of $98 for motor controllers.

Motor controllers are mounted atop the aluminum side bars with an acrylic plate underneath for insulation. Power wires are routed along the sides of the rover, meeting at the power distribution board mounted on the left wall of the rover.

The power distribution board was chosen to support seven branches of power, totaling W at 24V. The Power Battery ESC Board Distribution provided an extra power port and supported the 3A draw for each of the six motor branch branches. The seventh branch is designated for the 24V to 12V step down converter, also mounted on the left side of the rover's internal walls.

The output of the step down converter is routed to an acrylic plated mounted a foot higher than the motors.

More sensitive components are mounted here and consist of the Turnigy 5A (8V-26V) BEC power converter (15W), the Ubiquiti Bullet M2 Wi-Fi antenna (7W), and the Atom board (16W). The Atom board must be run at 12V and the BEC and Wi-Fi Antenna can also run at 12V. The Turnigy supplies 1.5A at 5V to the gimbal servos.

All three of these components require a steady voltage. A 24V to 12V 240W step down converter supplies the steady voltage source for these components, assuming roughly 90% efficiency gives a wattage consumption of 42W.

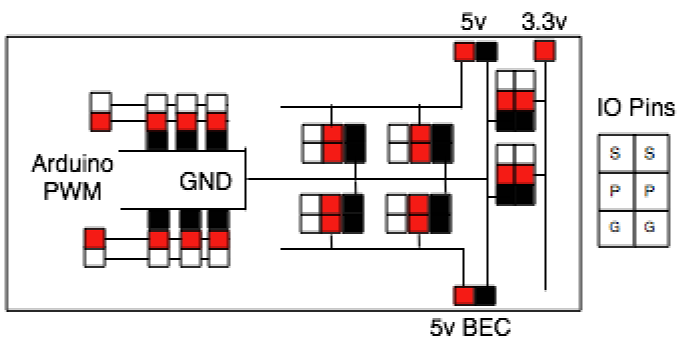
The power supply consists of two 12 volt 55 amp-hour lead-acid batteries. Assuming the total electrical load of 474W is run continuously, the batteries will last 2.75 hours.

480W/24V = 20 amps

55A*Hours/20 = 2.75 hours

4.2.4 Signal System

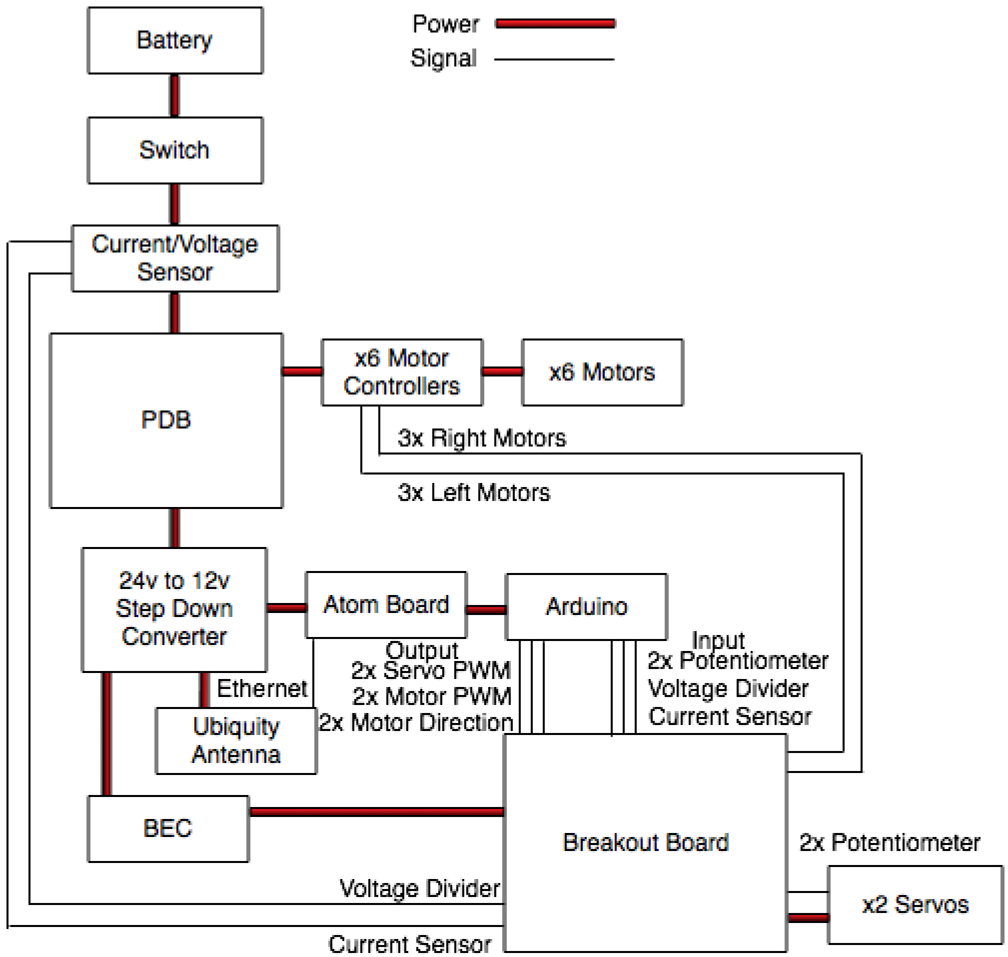
Control signals that regulate the motor controllers and gimbal servos stem from the Arduino. To connect the numerous control signals that come from the Arduino, our electronics team designed a breakout board to accommodate the 5V, 3.3V, and BEC 5v power supply.



The Arduino board is mounted on the inner left side wall of the rover while the breakout board is mounted on standoffs atop the left aluminum bar.

Two PWM signals correspond to the motors on each side. Three motors receive the same signal. 5V BEC voltage rail supplies power to the servos in the camera gimbal, while also passing the control signal to the servo. The 5V Arduino volta0ge rail powers the potentiometers while passing the signal voltage to the Arduino.

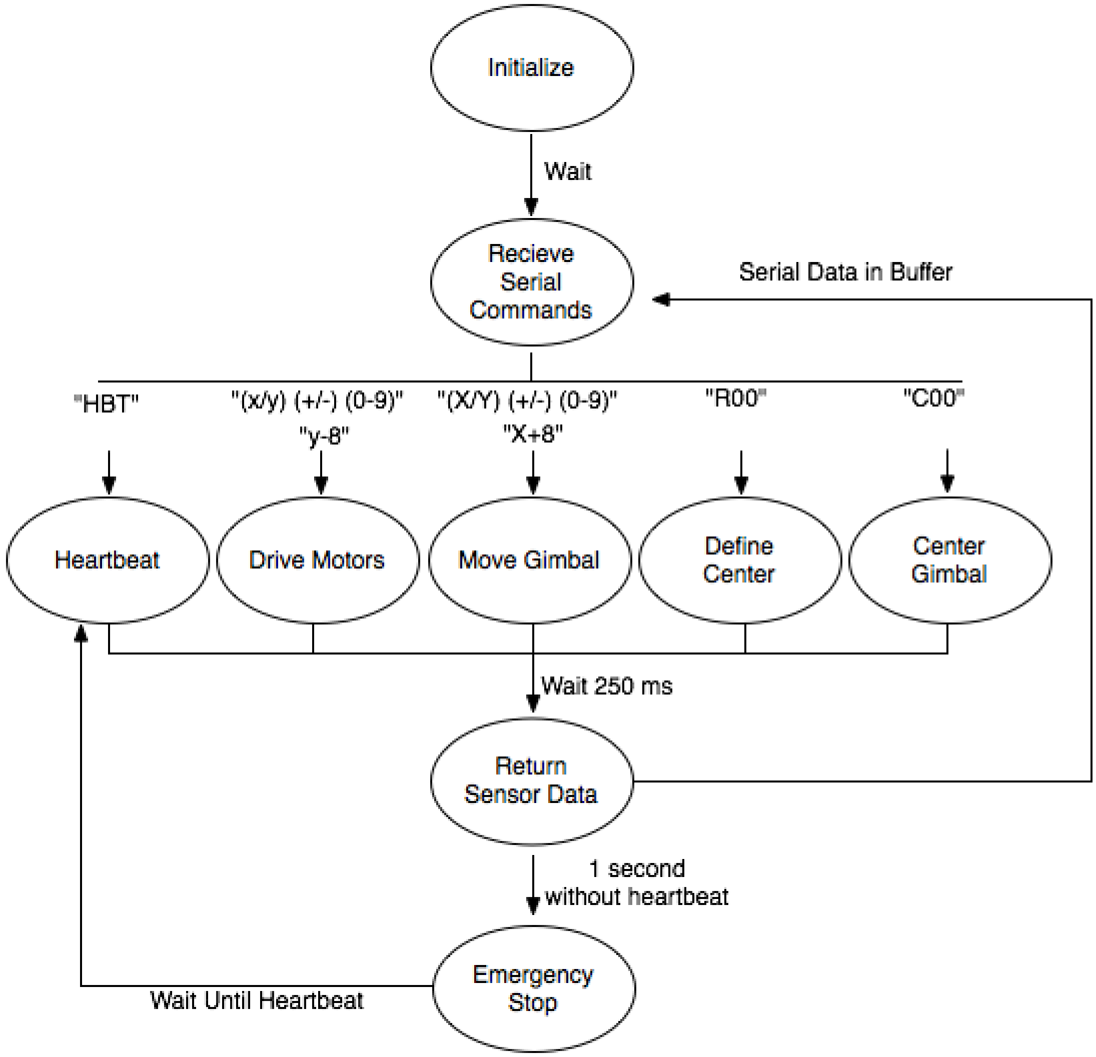
4.2.5 Power and Signal Wiring Diagram



4.3 Software

Arduino Code

The Arduino continually receives data from the Atom board via serial communication.

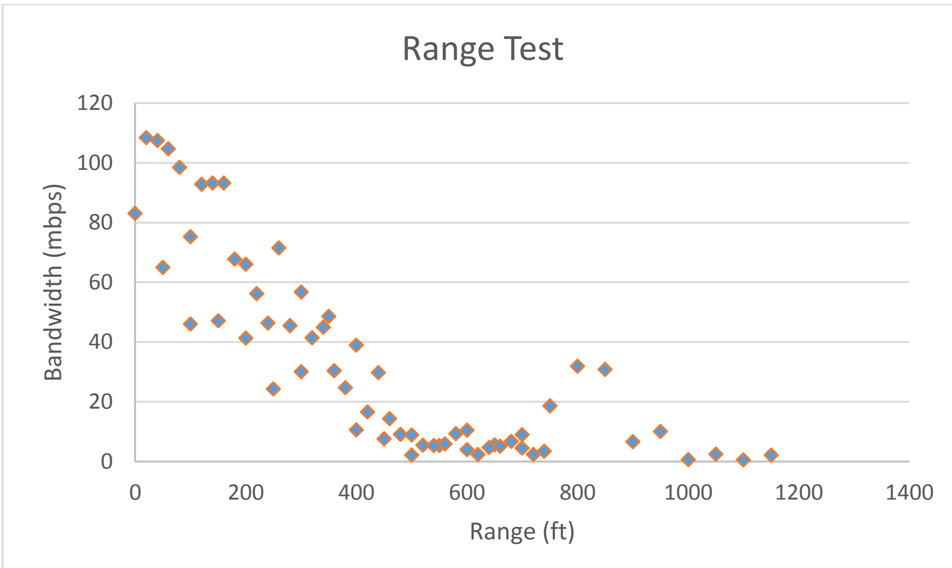


Server/Client-

In order to establish a live stream between the server and the client, we utilized OpenCV as a means of capturing and processing the camera feed from the robot. The stream is capable of stacking two camera feeds, such as thermal and night vision, creating a semi-transparent blend of both images. However, we are currently only utilizing a single camera feed due to complications with integrating the thermal camera with the Linux OS. The connection between the client and the server is established through socket programming. The client provides the IP address of the server along with the port number and the dimensions of the stream. The server remains idle waiting for an incoming connection request. As soon as the client connects, the server starts sending a compressed sequence of bits which is then decoded into a three dimensional matrix on the client side and displayed to the user as an image. If the client was to disconnect, the server will still stay up listening for another connection request. Therefore, in order to re-connect the user has to re-run the client.

During our first phase of testing the camera stream, our bandwidth consumption was about 10 Mbps. However, the Ubiquiti radios that we use to establish a connection between the client and the server could not support such a rate of transfer. This resulted in a stream with a significant delay, and would not operate beyond a 20 foot distance from the client. In order to resolve this problem we turned to Jpeg compression. By utilizing OpenCV's decoding functions we were able to minimize the transfer rate drastically, down to an average of 400 KBps. This drastically increased the range of the stream and provided minimal lag. However, the compression used is not without loss. Which means we sacrifice quality in return for a better transfer rate. However, the loss in quality is not noticeable and does not affect the user's experience. The compression also introduced a greater workload on the CPU. We dealt with this by introducing multi-threading, partitioning the tasks to different threads to increase efficiency.

Below is a graph illustrating a range test using the Ubiquity radios. This was sufficient to prove that we could easily sustain our video feed and controls at a range of up to 500 ft. Anomalies seen on this graph were caused due to nearby WIFI interference, as well as trees blocking the line of sight. This is not an issue at the wolf center as they do not have a WIFI network near the enclosure.



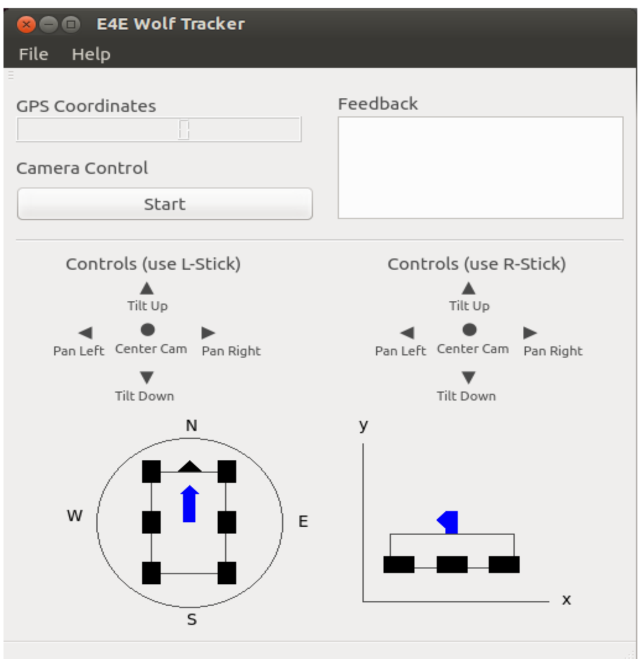
Audio was also an option that we explored. Using the openAL libraries, we managed to capture the audio from the camera and echo it. However, the design of the robot drastically reduced the quality of the audio. This is due to a dome shaped encapsulation design, which protects camera for external forces, and thus reduced the quality and range of audio that we could pick up.

Communication with the robot is established through a wireless Xbox 360 controller. We process the controller input in conjunction with an xboxdrv driver and the client side serial communication thread. The serial communication thread opens up a socket connection on a different port with the server and listens for controller input. Once the controller fires an event we process the button-value pair and send it to the server. The server then reads and parses the input as either a button or a joystick. If its a button then it writes the appropriate button character to the Arduino, else if it is a joystick then it rights the appropriate axis-value pair. Additionally, the server sends a heartbeat to the Arduino every half second to ensure that if the server malfunction then the robot will not continue moving. The top left joystick controllers the camera gimbal, the right joystick controls the motors, button Y closes the client software, button X re-centers the gimbal, and button B allows the user to redefine the center for the gimbal.

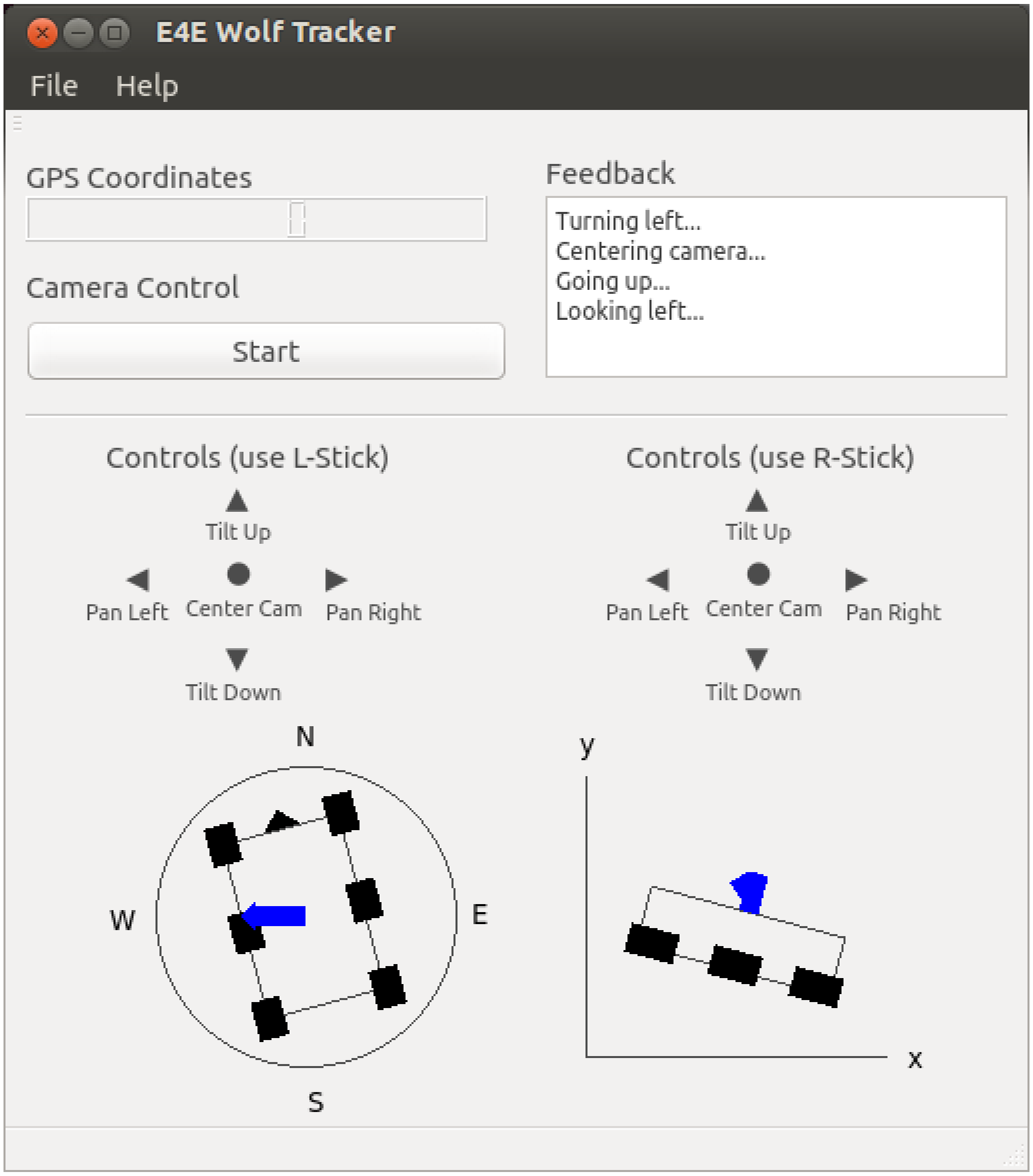
GUI-

- We utilized QT Creator in order to design our GUI for controlling the robot. Our user interface aimed to be a simple, but informative environment in order to aid the control of our rover. The top of our interface shows the GPS coordinates of the rover, a feedback panel which prints the current functioning status of the rover, as well as the start button in order to begin camera streaming and controls. Beneath, we have the basic control layout of the remote describing the joystick layout which allows the user to move the rover. At the bottom of the UI there is a graphical representation of the status of the robot. The left shows the compass direction of the robot as well as the orientation of the camera relative to the robot. The right shows the orientation (or tilt) of the robot allowing the user to view the approximate steepness of the terrain they are handing as well as a general idea of the status of the robot.
- Since the compass direction is based off of a magnetometer, the magnetic declination must be changed if there is a significant change in position. This value can be adjusted from the GUI in order to recalculate the true north in case the rover is relocated to another facility.

\- A screenshot of the default view of the GUI before the rover is started up.



- screenshot of the functioning GUI - aside from GPS information.



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- A screenshot of the help screen which explains the interface.

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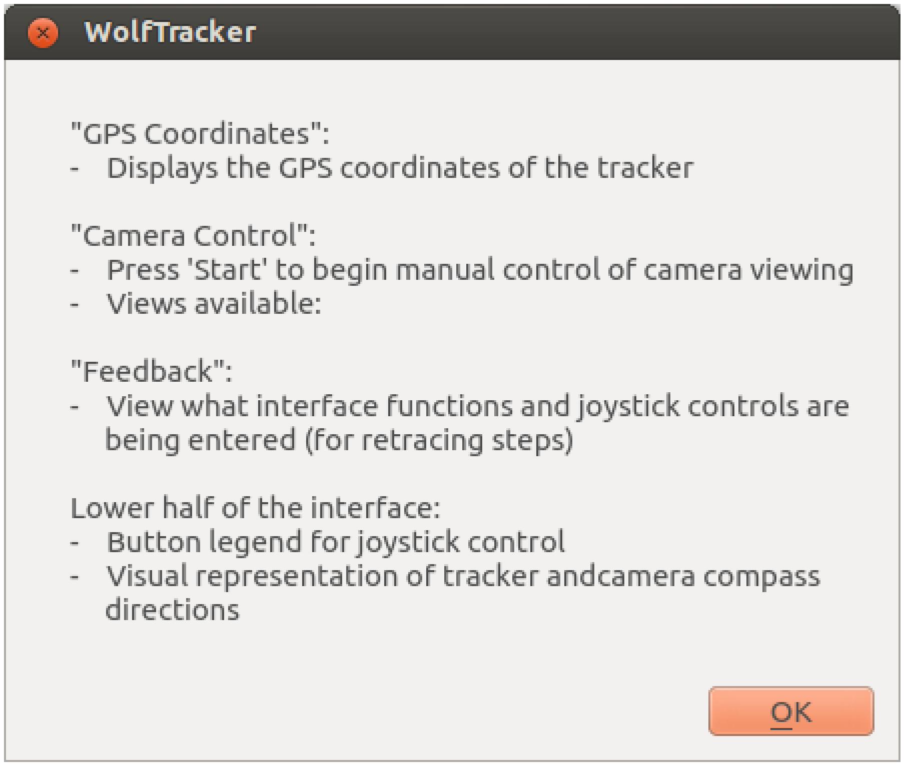

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5 Project Execution Overview

During the course of this project we encountered difficulties which we had to overcome. An initial problem was the organization of the team and the project. As will most likely be observed with multiple teams and projects, it is not always easy to combine different tasks, especially when there is a lack of communication. The biggest of those issues which were related to our project included the mismatch of some of the software and electronics together with the hardware. As a result we encountered the following problems:

Initially we were not certain whether we were going to be having problems of interference between the various electronic devices. The motors emitted conductive noise which could potentially have affected the wireless 2.4 Ghz antenna, as well as provided interference to the gimbal, and electronic systems, including the Atom board. We decide to overcome this problem, to consider use small resistors and ferrite beads, in the case that during testing, we would experience significant problems with interference.

For this particular project the selection of materials was challenging. When we were first designing the prototype, we outlined our priorities in terms of power output, ground clearance, toughness and financial viability. After the theoretical calculations were done, we decided that our best option were the IG52 motors with 12mm shafts and output of 23kgf-cm at a rated speed of 136 RPM. We overestimated the weight of our vehicle by 20 kg, as another safety factor for power, in order to be sure that it was going to able to handle rough terrain irrespective of amount of load and terrain angle.

For the selection of aluminum plates, we again had to overestimate the weight of our vehicle in order to be sure that it was going to handle its weight load. In the first designs of our project we agreed on using 2 12V deep cycle batteries that provided 55Ah. The problem was that each battery weighted 18kg, so structural rigidness was a priority at that time. For that reason we agreed on using ¼ inches for the bottom plate as to provide a more stable platform as well as minimize bending due to weight. As the design evolved, we decided to use smaller batteries, as we were able to sustain the runtimes we needed to achieve with a smaller capacity. As the batteries changed, the vehicle is more portable and is able to handle different amounts of loads irrespective of the battery selection. If in future we want to increase runtime of our vehicle, we can still replace the batteries to increase the amount of usage time without having to change the design of the vehicle. The battery location is modular, therefore larger batteries can easily be accommodated.

Testing of the prototype have been successful so far. We were able to deploy our vehicle and it managed to handle the terrain pretty well. The terrain at the California Wolf Center a in San Julian is quite rough, presenting diverse or heterogeneous types of terrain. It presents steep slopes, desert like areas with no vegetation, areas with the presence of big roots sprouting out of the terrain and big rocks, and others where there is a lot of grass and vegetation. More detail of the testing results can be seen in the next section.

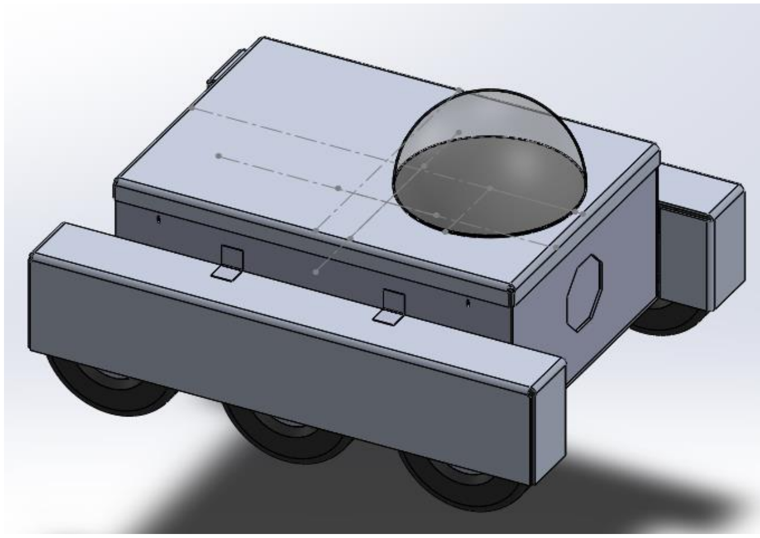
In terms of budget, we decided to minimize costs, to provide a platform which can easily be reproduced, and applied to multiple projects beyond the wolf center in the future. The major part of the cost is constituted by the aluminum sheets and bars, as well as the motors and wheels. The electronics remained cheap as we mainly used off the shelf, development products, and were able to use the Atom Board as our central controller. If desired, we can increase the resolution and image quality obtained by the rover, with the use of a DSLR mounted on the gimbal. The whole system is modular with the sensors we put onto it. The wireless transmission is able to handle higher bandwidth, therefore, a feed from a DSLR would easily work. The controls of different cameras can also be implemented through a simple trigger linked to the Arduino board. Below is a list of the components we purchased to build the rover:

Item	Link	Price	Quantity	Weight (lbs)	Total Price
IG52-04 24VDC 136 RPM Gear Motor[1]	http://www.superdroidrobots.com/shop/item.aspx/ig52-04-24vdc-136-rpm-gear-motor/872/	135	6	3.5	810
10 Inch Wheels with 12mm bore wheel hubs[2]	http://www.superdroidrobots.com/shop/item.aspx/atr-wheel-and-shaft-set-pair-12mm-bore-10-inch-pneumatic/1260/	100	3	6.6	300
Motorcontrollers	http://www.robotshop.com/en/cytron-13a-single-dc-motor-controller.html	16.33	6		97.98
No8 screws, bolts, wire[3]					
Type 316 Stainless Steel Socket Head Cap Screw Qty 25 Pcs[4]	http://www.mcmaster.com/#92185a194/=qqrggt	3.23	4		12.92
Type 316 Stainless Steel Socket Head Cap Screw Qty 5 Pcs[5]	http://www.mcmaster.com/#92185a217/=qqt3ru	4.48	4		17.92
Type 316 Stainless Steel Machine Screw Hex Nut Qty 100 Pcs	http://www.mcmaster.com/#90257a009/=qqt3a9	7.98	1		7.98
18-8 Stainless Steel Type A SAE Flat Washer Qty 100 Pcs[6]	http://www.mcmaster.com/#96659a103/=qqrgnq	3.89	2		7.78
No6 Screws, washers, and nuts for latches					
Type 316 Stainless Steel Socket Head Cap Screw	http://www.mcmaster.com/#92185a148/=qsivqb	2.62	2		5.24
Zinc-Plated Steel Machine Screw Hex Nut	http://www.mcmaster.com/#90480a007/=qsiymb	1.16	1		1.16
18-8 Stainless Steel Type A SAE Flat Washer	http://www.mcmaster.com/#96659a102/=qsiyza	3.44	1		3.44
M5 Screws for Motor	http://www.mcmaster.com/#92290a224/=qxfpa1	7.45	2		
Brackets					
F latch	http://www.mcmaster.com/#1889a43/=qqmba	6.65	4		26.6
inside corner brackets	http://www.mcmaster.com/#1088a33/=qqrjl8	3.68	10	0[7]	36.8
no 9 corner bracket 1' 1/2"	http://www.mcmaster.com/#17715a43/=qxfxqq	1.46	10		14.6
Multipurpose 6061 Aluminum T-Bar, .050" Thick x 1/2" High x 5/8" Wide 4ft. Long	http://www.mcmaster.com/#1668t22/=qxftrx	3.56	2		7.12
Clear Silicon Adhesive	http://www.mcmaster.com/#7545a472/=qxejd8	9.88	3		29.64
Aluminum Sheets and T bars					
Aluminum Faces Dimensions (in.)	Sheets to purchase				
36 x 24 x 0.25	http://www.onlinemetals.com/merchant.cfm?pid=1248&step=4&showunits=inches&id=76&top_cat=0	136	1	22	136
36 x 12 (2) x 3/16	http://www.onlinemetals.com/merchant.cfm?pid=1247&step=4&showunits=inches&id=76&top_cat=0	55.84	2	16.0876	111.68
24 x 12 (2) x 3/16	http://www.onlinemetals.com/merchant.cfm?pid=1247&step=4&showunits=inches&id=76&top_cat=0	43	2	10.725	86
36 x 24 x 3/16	http://www.onlinemetals.com/merchant.cfm?pid=1247&step=4&showunits=inches&id=76&top_cat=0	100	1	16.088	100
Aluminum square tube 2.5", 3ft, 0125 thick	http://www.onlinemetals.com/merchant.cfm?pid=18018&step=4&showunits=inches&id=1&top_cat=0	23.71	2	7	47.42
Fwlt Filterfor Fans	http://www.amazon.com/Singed-Polyester-Filter-Fabric-Micron/dp/B004JH9EUW	18.5	1		18.5
Total =				82.0006	1878.78

It has been difficult to get a consensus regarding design specifications, financial viability, and implementation. One of the biggest issues we had encountered is regarding deploying time and power consumption. When we agreed to make the project for the California Wolf Center, they suggested the idea of deploying the prototype for at least 4 hours. This meant that we had to come across a selection of batteries that could be reliable and at the same time provide enough power for the motors and the rest of the electronics. Our first selection of batteries were of a kind known as deep cycle, which are very reliable and would be able to provide short amounts of current for a long period of time (compared with regular car batteries). Our idea was to use two deep cycle batteries in-series of 12V each providing 55Ah and weighing 17.5kgs. The main problem with deep cycle batteries is that they are expensive and heavy. Having that in mind, we agreed to use them as they will be more than suited for the project. Fortunately, as we progressed with the project and did further testings, we realized that those batteries were actually more than what we needed. In the current version of our project, the batteries are smaller and lighter. Of course the prototype was designed to carry deep cycle batteries. If in case we need to increase deploying time in the future, we could easily just change the batteries without changing the design of the prototype.

Another issue that we need to consider with this project is a way to protect the wheels. Wolves have incredible powerful bites, sometimes able to achieve forces of over 400psi. With this in mind, we came across different ideas in order to protect the wheels.

The actual design we had in mind looks like this:

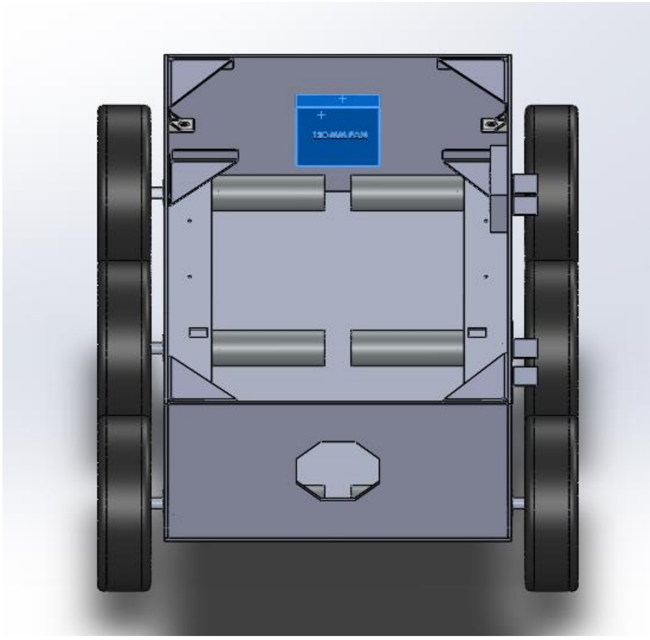


Unfortunately introducing wheel covers to the design led to further issues. With aluminum wheel covers we would actually increase the weight of the design and reduce the overall ground clearance of the vehicle. Even so, we decided that protecting the wheels was far more important and we agreed to stick with this idea. Unluckily for us, time and budget issues have played a big part in this project so the execution of wheel covers will have to be done in the future.

Another issue we encountered with our design was insulation and waterproofness. Some of the parts we cut and milled in the project were not executed 100% perfectly. We must be honest and say that there are one or two rough edges in the actual prototype, as we take into account that milling, designing, and executing a design not always go as planned. This introduced panel gaps on the rear side of the vehicle as we did calculations incorrectly and did not account for the extra space that the flanges take place in between the side plates and the aluminum bars. But this issues is more than negligible as the panel gaps can be fixed by soldering pieces or the introduction of foam.

The last problem we having solved regarding ventilation. The original design and further testings have suggested that the introduction of ventilation is necessary to the vehicle. In the CAD design we have included two holes, located at the front and back, for 2-12mm computer-like fans. In order to introduce them to the vehicle, we would need to include a filter system to prevent dust from coming inside the shell and harming the electronics. Unfortunately, we were unable to introduce the fan system on time but it will be definitely done in the future as we have the materials ready to do so.

Design looks like this, with one of the fans highlighted and the other one removed:



Below is an image of us investigating the reaction of the wolves to the vehicle outside their enclosure:

6 Recommendations and Next Steps

The project is going to continue after Cornell Cup. The aim is to continue collaborating with the California Wolf Center until the researches have gathered all the data they need to conclude a certain behavior of the wolves at night. From the tests which were run until now, the following small improvements need to be done to the vehicle before all tests can be run inside the enclosures of the wolf center.

The wheel covers need to be added to the vehicle, to prevent the wolves having access to the tires, which they might consider as toys. This is damaging to the vehicle itself, however it may also incur habits the wolves should not get into.

Furthermore, all the corners and joints need to be sealed with silicon to make sure that the vehicle is waterproof to the extent we need it to be for longer tests. Equally, nylon bolts will be added to increase the enduring strength of the assembly. It happened that a bolt fell off after a serious amount of transportation. All of this will be finalized after the competition, as the vehicle will not be disassemble again afterwards.

In the longer run, we will upgrade battery capacity, and will consider using Lithium Polymer batteries, which have a higher energy density, increasing the potential operation time of the vehicle to multiple days. This is particularly interesting for other projects this vehicle might later be used for.

For the Wolf Center, the researchers have expressed an interest in doing some cinematography and photography after having run all their behavioral tests. To do so, they will be mounting a DSLR inside of the dome, and shooting at a much higher resolution. This can be done both during daytime, and nighttime.

If we were going to develop this project significantly further, we would add the sensors necessary to make this vehicle completely autonomous. This would include a LIDAR sensor to detect any bushes, holes or other obstacles. We could also consider improving the clearance, of the rover to better handle rough terrain with roots and rocks. This would require a significant level of testing and improving to ensure that the vehicle behaves according to the environment. Equally it is important that in case of a problem, the system would follow a procedure such as to protect itself.

The timeline of this project will include data collection over the next weeks and months at the California Wolf Center. Some of this testing will be done with students from this project to ensure that all technical aspects run smoothly. In addition, this time will serve as training for the researchers to use this vehicle on their own. If everything runs well in the next few tests, we will hand this vehicle fully to them for operation for multiple months. After we have completed our work with the Wolf Center, we are looking at deploying this vehicle in other countries, including Namibia, Guatemala and all across North America. This platform has had tremendous success so far, and multiple external researches have expressed the desire to work with it. Due to its simple manufacturing and cheap cost, this vehicle can quickly be multiplied and deployed around the world.

7 References

"Using the Accelerometer – HUSSTECH." HUSSTECH. Husstech, n.d. Web. 21 Apr. 2014.

"9 Degrees of Freedom - MPU-9150 Breakout SEN-11486 RoHS Open Source Hardware Has 3D Model." 9 Degrees of Freedom. SparkFun, n.d. Web. 21 Apr. 2014.

"High Performance Active GPS Antenna." - CSG Shop. N.p., n.d. Web. 21 Apr. 2014.

"UBLOX NEO-7N GPS/GNSS Receiver Board with SMA for UAV, Robots." - CSG Shop. N.p., n.d. Web. 21 Apr. 2014.

"DIY Amp / Watt Hour Volt Meter - Arduino." Instructables.com. N.p., n.d. Web. 21 Apr. 2014.

Further Readings

Bares, J. E., et al. "Ambler: An autonomous rover for planetary exploration" *Computer* 22.6 (1989): 18-26.

Lacroix, Simon, et al. "Autonomous rover navigation on unknown terrains: Functions and integration." *The International Journal of Robotics Research*21.10-11 (2002): 917-942.

Howard, Ayanna, and Homayoun Seraji. "Real-time assessment of terrain traversability for autonomous rover navigation." *Intelligent Robots and Systems, 2000.(IROS 2000). Proceedings. 2000 IEEE/RSJ International Conference on*. Vol. 1. IEEE, 2000.

California Wolf Center. Web. Oct 17 2013. <http://www.californiawolfcenter.org/about/contact/>

UCSD Engineers For Exploration. Web. Oct 17 2013 <http://e4e.ucsd.edu/wordpress/?page_id=2>